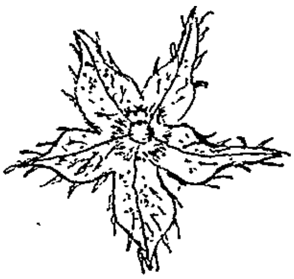
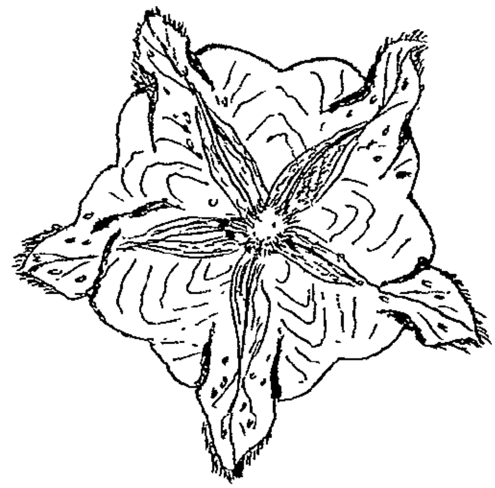
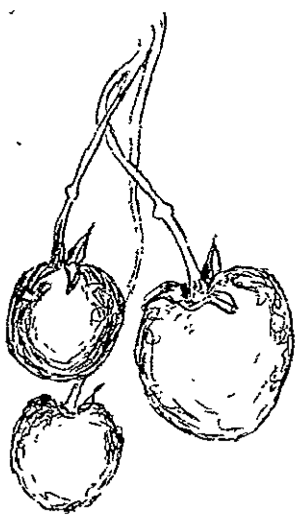
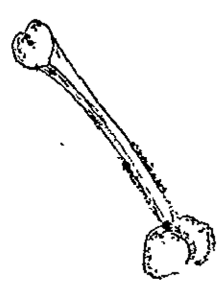




POTATO PROTEIN QUALITY



REPORT OF THE INTERNATIONAL POTATO CENTER'S PLANNING CONFERENCE ON POTATO QUALITY



INTERNATIONAL POTATO CENTRE INTERNACIONAL DE LA PAPA

LIMA - PERU

INTERNATIONAL POTATO CENTER (CIP)

REPORT OF THE

POTATO QUALITY PLANNING CONFERENCE

Held at CIP - Lima, PERU

November 26-30, 1973

IN MEMORIUM

This Report is dedicated to the memory of

Dr. Robert Luescher

who died on March 8, 1974, following a brief illness. The "Genetic Variability of "Available" Methionine Total Protein, Specific Gravity and Others Traits in Tetraploid Potatoes", the subject of Dr. Luescher's thesis (1972), served as the basis for his outstanding contribution to this Planning Conference. The microbiological techniques for assessing the nutritive qualities of the potato were developed through Dr. Luescher's research prior to joining CIP in October, 1973.

His approach to life and to his work can serve as an example to all of us.

CONTENTS

PLANNING CONFERENCE ON POTATO QUALITY

Held at CIP, Lima, November 1973

At the request of Dr. Richard Sawyer, Director General of "El Centro Internacional de la Papa", a Planning Conference was held to examine priorities and recommend specific programmes for the nest five years on potato quality.

This document summarizes the discussions and recommendations, indicating research priorities and suggesting sources from whom cooperation might be sought to successfully complete the envisioned goals.

Participants in the Planning Conference were:

Dr. Ora Smith, Chairman	Professor Emeritus, Dept. of Vegetable Crops, Plant Science Building, Cornell University, Ithaca, New York, U.S.A.
Dr. W.G. Burton	Agricultural Research Council, Food Research Institute, Colney Lane, Norwich Nor 70F, England, GREAT BRITAIN.
Dr. Antonio Bacigalupo	Director of Research, National Agrarian University, Apartado 456, La Molina, Lima, PERU.
Dr. Max Milner	PAG Secretariat, Room A-606, United Nations, New York, New York 10017, U.S.A.

Dr. Sharon Desborough	Laboratory of Plant Hardiness, Dept. of Horticultural Science, University of Minnesota, St. Paul, Minn. 55101, U.S.A.
Dr. J.E. Hoff	Agricultural Experiment Station, Department of Horticulture, Purdue University, Lafayette, Indiana 47907, U.S.A.
Dr. C.A. Ryan	Dept. of Agricultural Chemistry, Washington State University, Pullman, Washington 99163, U.S.A.
Dr. M.S. Kaldy	Canada Department of Agriculture, Research Station, Lethbridge, Alberta, CANADA T1J 4B1.
Dr. Eugene A. Talley	Eastern Regional Research Center, 600 E. Mermaid Lane, Philadelphia, Penn. 19118, U.S.A.
Dr. Magnhild Umaerus	The Swedish Seed Association, S-268 00 Svalov, SWEDEN.
Dr. N.R. Thompson	Dept. of Crop and Soil Sciences, Michigan State University, East Lansing, Michigan 48823, U.S.A.

CIP personnel participating in the Planning Conference were:

Dr. Robert Lüscher	Nutritional Breeder
Dr. William Roca	Physiologist
Dr. Paul Li	Physiologist
Dr. O. T. Page	Associate Director - Research
Dr. P. Roger Rowe	Head, Plant Breeding Department

Back row : Drs. Hoff, Talley, Ryan and Li

Middle row: Drs. Desborough, Kaldy, Thompson, Umaerus and Roca

Front row : Drs. Milner, Smith, Burton and Page

INTRODUCTION

The potato is the fourth most important food crop in the world. Per hectare it produces, an average, more dry matter than the legumes and more than any of the cereal crops except maize, which exceeds it by some twenty per cent. Nutritionally the potato is perhaps the most balanced of the major food crops in that it provides calories and nitrogen in proportion to adult human requirements, coupled with a sufficiency of vitamin C and considerable amounts of some B- vitamins.

The potato has the disadvantage in comparison with the cereals in that it is more perishable after harvest. A spectrum of processed products has been developed which now permits the excellent nutritive characteristics of the potato to be retained over relatively long periods of storage. While many processing techniques require sophisticated equipment, some progress is being made in developing procedures which are applicable to small-scale village processing in developing countries.

Prior to the Planning Conference on Potato Quality a number of CIP personnel met to discuss some items of particular interest to them. The proceedings of this meeting were formulated as a series of questions that are indicative of problems confronting CIP in its efforts to improve potato quality. It is informative to consider some of these questions relating to research to improve quality:

A. <u>Cultural Procedures:</u>

1. Is the phenotypic expression, relative to protein production, best evaluated under experimental conditions with or without the addition of nitrogen fertilizer ?

2. What is the availability of nitrogen at zero level addition of fertilizer ? Should a standard soil test be used and nitrogen added to some arbitrary level ?

3. Which mechanism limits the initial control in protein synthesis: nitrogen uptake and/or translocation ?

4. What new equipment do we need for application of fertilizers ?

5. Should quality assessment be under conditions appropriate only to developing countries: - no highly specialized breeding program; short days; low-fertilizer availability ?

6. Are there cultural practices which may be used by more primitive agriculture to raise protein content ?

B. Screening Procedures:

1. What nitrogenous compound (s) do we screen for ? What sequence would be used in screening: -- total N-dry matter; specific gravity; quality assessment by microorganisms; methionine level; etc. ?

2. What is the most rapid way to screen for protein level and quality in a large number of clones, i.e. 4,000 - 10,000 ?

3. What genetic sources of diversity should be considered ? What is the current status of protein level in potato varieties cultivated in Peru ? What is the level in the late blight resistant material available in Toluca, Mexico ? What Solanum species are to be examined ?

4. Is screening designed to identify genetic sources of high nutritive value at harvest or should screening also include the influence of storage ? Is there anything that can be done by genetic manipulation to modify potential changes in storage ?

5. Should an arbitrary goal be set regarding the level of protein content to be achieved ? Are lower limits for nutritional quality to be established ?

6. What is the priority of protein level versus disease resistance ?

7. Are levels of antimetabolites such as solanines and phytate to be evaluated during screening ?

8. How do we measure progress in a complex breeding program relative to general quality improvement ?

While these questions provide an insight into some of the factors to be considered in cultural and screening procedures, similar questions can be raised concerning methods of processing potatoes for storage in developing countries. In addition, detailing precise methods for analyzing potato quality requires a critical evaluation of procedures used in chemical analyses of other food crops as well as an intimate knowledge of the nitrogen and carbohydrate metabolism of the potato plant.

For purposes of organizing the Planning Conference on Potato Quality, the following four areas were designated for discussion:

I. Protein - increasing quantity and quality. This includes breeding techniques, the

effect of fertilizing, seasonal variations, soil type, maturity, nutritive value and, other items.

II. Potato quality factors other than protein. In this section are included the chemical composition of potatoes, their nutritional value and effects of methods of cooking on nutritive value.

III. Processed quality of potatoes. This includes how the food value of the potato is affected by the various forms of processing.

IV. Chemical analyses used for determining potato quality.

* * * * * *

I. Protein - Increasing Quantity and Quality:

The nitrogen of the potato is combined in many forms of which protein, including the enzyme protein, nucleic acids, free amino acids and amides, and anti-nutritional compounds such as solanidine and its derivatives are of direct relevance to the nutritional quality. Total nitrogen, in that it includes material which is probably of no nutritional significance (such as cell wall protein) or of anti-nutritional significance, cannot be taken to give an estimate of the nutritive value of the tuber, unless it can be shown directly correlated with the nutritionally available nitrogen.

Tuberosum cultivars in Europe and North America are at least as good a source of available nitrogen (based on the amount of potatoes required to maintain nitrogen balance in the adult human male) as of calories. The quality of the protein, with respect to most of the essential amino acids is very good, but there is a deficiency of sulfur - containing amino acids. Taking average values of analyses of European potatoes, the daily requirement (adult 70- g male) for most essential amino acids would be met by the consumption of less than one kilo of potatoes and in many cases by little more than 0.5 kilos, although a consumption of about 2.5 kilos would be needed to give the requirement of sulfur-containing amino acids. The daily requirement of calories would be provided by about 3 - 3.5 kilos, depending upon whether one takes the requirement as 2,500 or 3,000 calories.

The variability that has been found just within Tuberosum cultivars indicates that there is a potential for greatly increasing both the content of protein and of methionine

in the protein. However, because the potato already contains protein in quantities as great or greater, relative to the requirements, as those of other nutritionally important constituents (other than vitamin C, of which it is a very important source), breeding for increased protein, or increased methionine, should for utilization in the developed countries be followed only so far as it is compatible with the achievement or retention of other qualities such as disease and insect resistance, productivity, wider adaptability, and improved processing and consumer acceptance characteristics. In the developing countries it is possible that circumstances may exist that will make high protein content preferable to some of the other criteria of selection such as productivity or improved processing characteristics. In this respect it must be admitted that results to date have not shown great promise of achieving a combination of high yield (ie. fresh weight per hectare), high dry matter and high protein, in that there is sometimes a negative correlation between yield and crude protein, and no correlation between total nitrogen and dry matter. On the other hand, methionine, which can be taken as limiting the value of the potato as a source of protein, shows no negative correlation with yield and there would seem to be some promise of combining adequate yield, medium dry matter (of the order of 20%), and high methionine. Particularly if one extends beyond the Tuberosum cultivars, the potential for high protein is much increased and it may be possible to combine a high yield with a protein content or, more importantly, a methionine content, which, though it may be towards the lower limit of the potential range of, say, S. phureja is nevertheless higher than the present norm.

With respect to the CIP collection, one objective may eventually be to determine the content of available protein, the amino-acid pattern of the protein and the free amino-acids, of those members of the collection which appear from preliminary analyses to be most promising. It would be inconceivable to perform detailed analyses on the collection as a whole. Preliminary analyses should include dry matter, total nitrogen and protein nitrogen determinations (Appendix I) and could with advantage include determination of the electrophoretic pattern of the protein by acrylamide gel electrophoresis. This is quick and simple and provides a means of "finger-printing" the varieties in the collection (see J.A. Zwartz, 1966, Eur. Potato J. 9 , 111-128; S. Desborough and S.J. Peloquin, 1968, A. Potato J. 45, 220-229; V. Mac o and H. Stegemann, 1969, Hoppe-Seyl.Z. 350 , 917-919; R.M. Zacharius et al., 1971, Am. Potato J.48 , 57-63). There should be, on selected samples, a microbiological determination of the relative nutritive value with reference to casein. This last could be coupled with estimations of "available" methionine and, preferably, "available" cystine also (Appendices II and IV).

Potatoes are scarcely ever the sole source of nitrogen in the diet, and the supplementary value of potato protein in combination with other food protein should be assessed on a limited amount of material. The "other food protein" should be chosen on the basis of its relevance to the diet of the areas with which we are primarily concerned - legumes, milk, egg, chicken, fish, pig - meat spring to mind. In this connection the findings of kofranyi are of importance (1971, Proteins Food Supply Repub. S. Afr. Pap.

Int. Symp. 1968, 345-353; 1972, Melsunger Med. Mitt. 46, Suppl. 1, 15-23). Of the natural protein sources he tested, egg protein had the highest biological value, but potato protein was nearly as good, while a mixture of egg protein and potato protein in the ration of 7:13 had a higher value than either of the constituents, and higher than any other mixtures tested. There are optimal proportions of amino acids in the diet, and any deviation from these proportions results in a decrease in biological value of the protein. A mixture of egg and potato proteins in the above ratio gives a more nearly optimal proportion of the amino acids than either egg or potato protein alone. These findings have relevance to a breeding programme which could be devoted to changing not only the amount but the composition of the protein in the potato.

Prior to the release of breeding material as part of the outreach programme, or of clones for cultivation, the glyco-alkaloid content should always be checked, and material with an undesirably high content discarded.

II. <u>Potato Quality - Factors Other than Protein:</u>

If we are concerned primarily with food value other than protein, the relevant factors are available carbohydrates, vitamin A., vitamin B, Vitamin C. The first and last of these are of particular importance in the potato.

The content of available carbohydrates (mainly starch) is usually derived from the total content of dry matter by using a factor which in general, approximates three quarters of the dry matter. Cell wall material, reported as amounting to about 1% of the fresh weight (say 5% of the dry weight), is nutritionally unavailable but may have importance as fibre in the diet. In analysing the main bulk of material for available carbohydrates it would be adequate in the first instance to determine total dry matter and apply the appropriate factor. Supplementary analyses on selected material could with advantage include direct determinations of cell wall material.

The percentage dry matter of mature tubers in commerce ranges from about 17 - 27. Higher values of 30% or thereabouts have been achieved. There is thus scope for increasing the percentage dry matter of the crop from the 22 - 23% usual in Europe and the 20 - 22% common in North America. It must be remembered however that the factor of importance in potato production is the production of dry matter per hectare and that a negative correlation has been demonstrated between yield and percentage dry matter. Increase in dry matter content must only be sought if it is accompanied by a less than proportionate decrease in yield. In other words one must concentrate on yield of dry matter per hectare.

Vitamin C is present in the freshly harvested potato in amounts ranging from about 20 - 40 mg per 100 g fresh weight. There is a rapid decrease after harvest and a level of about 8 - 10 mg per 100 g is eventually reached. Despite this, the quantities

eaten render potatoes one of the most important, perhaps the most important, source of vitamin C in communities in which the potato is a staple foodstuff. Little is known of varietal differences in rates of vitamin C loss in storage or of content at harvest.

It was noted by participants that the potential contribution of the potato to the human requirement for vitamin A could be up to 30% per kg consumed in the case of yellow-fleshed varieties. These contain up to ten-fold the amount present in white-fleshed varieties. Judging from breeding efforts with the tomato and the sweet potato it would appear that the chances are good for increasing even further the vitamin A content of the potato.

Apart from nutritive value, the contents of reducing sugars, citric acid, iron and phenolic substances such chlorogenic acid, are of importance in specific respects - for example, after-cooking non-enzymic blackening of cooked potatoes results from a chlorogenic/iron complex. Citric acid reduces the blackening by chelating the iron and is also of interest as a by-product in, for example, starch factories. Reducing sugars are of over-riding importance in determining the quality of potato chips. Sugar content and content of phenolic substances and the susceptibility to accumulate sugars at low storage temperatures ($<5°C$) are all heritable. Internal bruising is of very great importance in the developed countries where potato processing is widespread. This results from enzymic blackening in areas where cell breakage has occurred following impact. The fragility which leads to it appears to be heritable.

III. Processed Quality of Potatoes:

Proper storage of potatoes in many parts of the world is very poorly developed or is nonexistent. Along with the development of storages and storage methods it would be well to extend the season of availability of the potato for consumption by preserving the potato in some processed form which could be stored fairly easily and reconstituted or combined with other foodstuffs by uncomplicated methods.

These methods of preservation, most likely some form of dehydration, must be by simple techniques and relatively easily accomplished at the village level. The products should be less perishable than the original potato and also preferably, with little or no loss in nutritional value.

Probably none of the above qualifications is met in the developing countries at present. Ancient methods of preservation such as making the various forms of chuño and related products result in extending the season of utilization of the potato but result in tremendous loss in nutritional value. Perhaps losses as high as 45% protein, 90% loss of sugars and 50% loss of minerals occur in these processes. Perhaps several methods of storing potatoes unprocessed should be considered here also.

A. Storage Methods

1. One method which has been used successfully in several areas is to delay harvest of the crop although it has reached complete maturity. In areas where irrigation is utilized the water is withheld so that the potatoes mature at a desirable time.

2. Storage structures: In many areas very simple storage structures would enable the grower to extend the period of marketing or personal utilization of potatoes. This may be in the form of rather thick walled structures of, for example, adobe, mud or heavily insulating materials such as thatch. Where day and night temperature variation is adequate, these structures could be built so that natural cooling of the air and potatoes in the storage could be attained by opening vents or doors at night.

   In some countries the necessity for long storage time would be reduced by growing two crops of potatoes in a twelve month period.

3. Potential methods of processing: Dehydration in some form appears to be the most likely method to extend the season of utilization of the product under dry climate conditions or where suitable packaging materials are available as moisture barriers. Some of the methods of potential value might involve simple procedures such as the following:

   a. Whole unpeeled potatoes could be boiled and peeled, and the produce mashed or extruded into rice or ribbon form and dried in an oven to at least 10% moisture. This product could remain in edible form for several months, though not at high tropical temperatures at which excessive caramelization would occur at a moisture content of 10%. Both this and possible browning during drying may be reduced by the addition of, for example, sulphite. This, however, may not be practicable in the areas under consideration in this Conference.

   b. Other forms of extruded products might be considered. Snack foods made from corn and other grains are processed by forming a dough-like product which is extruded under high pressure into a dry edible form. Perhaps the potato could be processed into a similar form. The potato could be macerated and the pulp added to grain meal or flour, made into dough and extruded under high pressure. This product also would have to be dehydrated to about 10% moisture.

   c. Products made from mixtures of cereal flours and cooked potatoes such as several baked semi-dry crisp dry products known in Scandinavia have good keeping qualities and may be considered for other regions

where fuel is not a limiting factor.

d. Solar drying to produce fla es appears to be a practical processing. technique although vitamin A content may be destroyed.

Any practical method of preservation will need to be adaptable to the use of very simple forms of machinery and equipment, preferably that which can be made in the community where it is to be used. Low cost hand operated grinders and macerators are available on the market and some simple forms of drying ovens could be made on the spot. It would not be difficult to fabricate such items as a press or other similar equipment for extruding any of the products in the form of dough.

Consideration should be given to the possibility of processing products of extended edible life which are made from potatoes in combination with grains. Such products might be "papa pan", noodles, and other extruded products which utilize any of the available grains, flour, meal, etc.

Conditions vary greatly between the countries and areas in which CIP is interested. Eating habits, combination of the foods now consumed, availability of companion foods, etc., are some of these factors. Perhaps some studies should be made in this area, the results of which may describe where greatest emphasis should be placed as to form of processed crop which would be readily accepted.

Any new processed product which is developed should, of course, be investigated as to its nutritional value. This research would closely follow the procedures for determining the nutritive value of raw potatoes as described in another section of this report.

Perhaps it would be well to encourage investigations on processing techniques in some of the institutions in other countries including the outreach countries. Research in this area should be conducted by well trained food technologists. This may best be done through linkage projects with wellsselected institutions..

IV. Chemical Analyses Used for Determining Potato Protein Quality:

Inherent in considerations of analyses of potato quality are such factors as methods of sampling, components of protein quality to be assessed, analytical techniques, the influence of fertilizers, and the number of clones to be assessed. Discussion was concentrated primarily on the assessment of methods of analyzing protein in screening a large number of clones such as are being accumulated by CIP at La Molina.

(i) Influence of fertilizer: Since the nitrogenous components of potato tubers are influenced by nitrogen fertilizer, it is important to establish some standard

level of nitrogen availability to minimize stress during growth, to provide a basis for comparative analyses among clones, and to permit rational comparisons of clones from season to season. In consideration of the complexities of soil nitrogen availability, with and without amendment by nitrogen fertilizer, and of such variables as assimilation and transport of nitrogen in the plant, it was concluded that an "adequate" level of nitrogen fertilizer should be applied to field plots. The level was to be determined by practical guidance and in such manner as reliable soil analyses might dictate. Clearly, nitrogen fertilizer amendment was considered essential, to be quantitatively broadcast prior to planting, but careful thought should be given to the level, as effects of this on the content and proportion of essential amino acids in the protein have been reported (B. Mica, 1971, Potato Res. 14, 19-28).

(ii) Methods of sampling: In common with many other factors that were discussed, it is difficult precisely to delimit sampling methods. In evaluating possibly more than 4,000 clones a rapid method is obviously imperative. Since clones may have different growth periods to maturity, clones should be harvested immediately following the death of the foliage. Thus different clones would be harvested at their approximate mature state as determined by weekly inspections. A succession of different clones would be processed in an orderly fashion. At harvest, tissue samples would be obtained by non-destructive removal of longitudinal wedges from apex to stem end and to a depth to the center of a tuber. These fresh samples would be immobilized by immersion in liquid nitrogen, or by freeze-drying, or preferably by placing in hot 70 - 80% alcohol. It is suggested that samples be powdered following freeze-drying and, when possible, standard amounts of powder of known moisture content be taken for analyses.

The possibility of expressing juice from cylinders of tuber, or some other configuration of tuber tissue may have merit in sampling for protein analyses. Early results have indicated that this technique should be further refined as it lends itself to evaluation of soluble proteins by means of refractometric determinations. Sucrose units, expressed as a protein index, correlated very favorably with proteins determined by the Lowry method; the per cent protein refractometer index versus per cent protein by Lowry had a value of r = 0.83 (Figure 1). It is proposed that sampling and protein evaluation by the above procedures might be further investigated through an appropriate linkage project.

(iii) Analytical techniques: During prolonged discussions of techniques to evaluate selected nitrogen-containing components of potatoes it became apparent that methods used in evaluating protein fractians of cereal seeds were not directly applicable to evaluating protein in a modified stem. The type of proteinacious substance to be evaluated, the importance of type and source of the amino acid fraction, the method of analysis, and finally, the end point

desired in protein assessment were considered.

The following components of tuber protein and methods of analyses were discussed:

1. Crude "protein" or nitrogen x 6.25 (or 7.5)
2. Peptides
3. Free amino acids
4. Dye binding capacity of proteins
5. Soluble protein
6. Bound protein
7. Net protein content (Per cent protein x 6.25 x Digestibility x Biological value) = Relative Nutritive Value

The following tests for determining protein in routine screening were considered the most appropriate:

1. Determine Specific Gravity of a sample.
2. Determine crude "protein" and true protein (by alcohol precipitation) on all samples, using micro-Kjeldahl technique.
3. Determine digestibility and biological value of component amino acids by micro-biological assay, on selected samples.

Other methods of assessing various peptide or amino acid components were rejected. However, protein assessment, as well as starch, lipid and water determinations by means of the Neotec instrument have the merit of permitting extremely rapid quantitative measurements. This approach for assessing total protein as a screening technique should be pursued. In addition, the removal of soluble protein, by acidified alcohol precipitation, prior to micro-Kjeldahl determinations, should be examined.

In screening for protein it is recommended that clones exhibiting less than ten per cent crude "protein" in the dry matter, as determined by micro-Kjeldahl, be eliminated from further protein evaluation. The expression of protein yield as a function of total solids produced per hectare is to be encouraged.

The necessity of evaluating potato protein in biological terms, in addition to purely chemical assessment deserves special emphasis: In a basic screening program the relative nutritive value with reference to casein can be determined by total growth of the bacterium, Streptococcus zymogenes. During this screening "available" methionine can also be assayed with S. zymogenes. If desired, "available" cystine can hopefully be assayed by a bioassay technique using the bacterium Clostridium welchii. The protozoan, Tetrahymena pyriformis may be used in secondary evaluations, this organism exhibiting specific requirements for the ten amino acids generally regarded as essential for the growth of man.

RECOMMENDATIONS

The techniques involved in making crosses to improve the nutritional quality of potatoes are not considered in Recommendations. But it is stressed that data derived from chemical and biological evaluation of nutritional quality are to provide the basis for selecting parental material. It was however emphasized repeatedly during the Conference that disease and insect resistance has priority over other properties in making crosses and selections particularly when these are destined for countries where specific diseases are a problem. Also, high dry matter per hectare has priority over a high content of protein.

Emphasis throughout the Conference was placed on protein quality and methods of evaluating quality. The quantitative aspects of protein, carbohydrates and vitamins were also considered. It was generally conceded that it was not difficult to obtain adequate levels of carbohydrates, that a minimum "cut off" for protein be established at 10% crude "protein", that a sufficiency of vitamin C was normally present and that vitamin A content could be improved. Attention should be directed to levels of anti-nutritional factors - phytate perhaps, but particularly the glyco-alkaloids. Material with anti-nutritional factors beyond accepted tolerance limits should not be released to countries which do not possess adequate facilities to assess them.

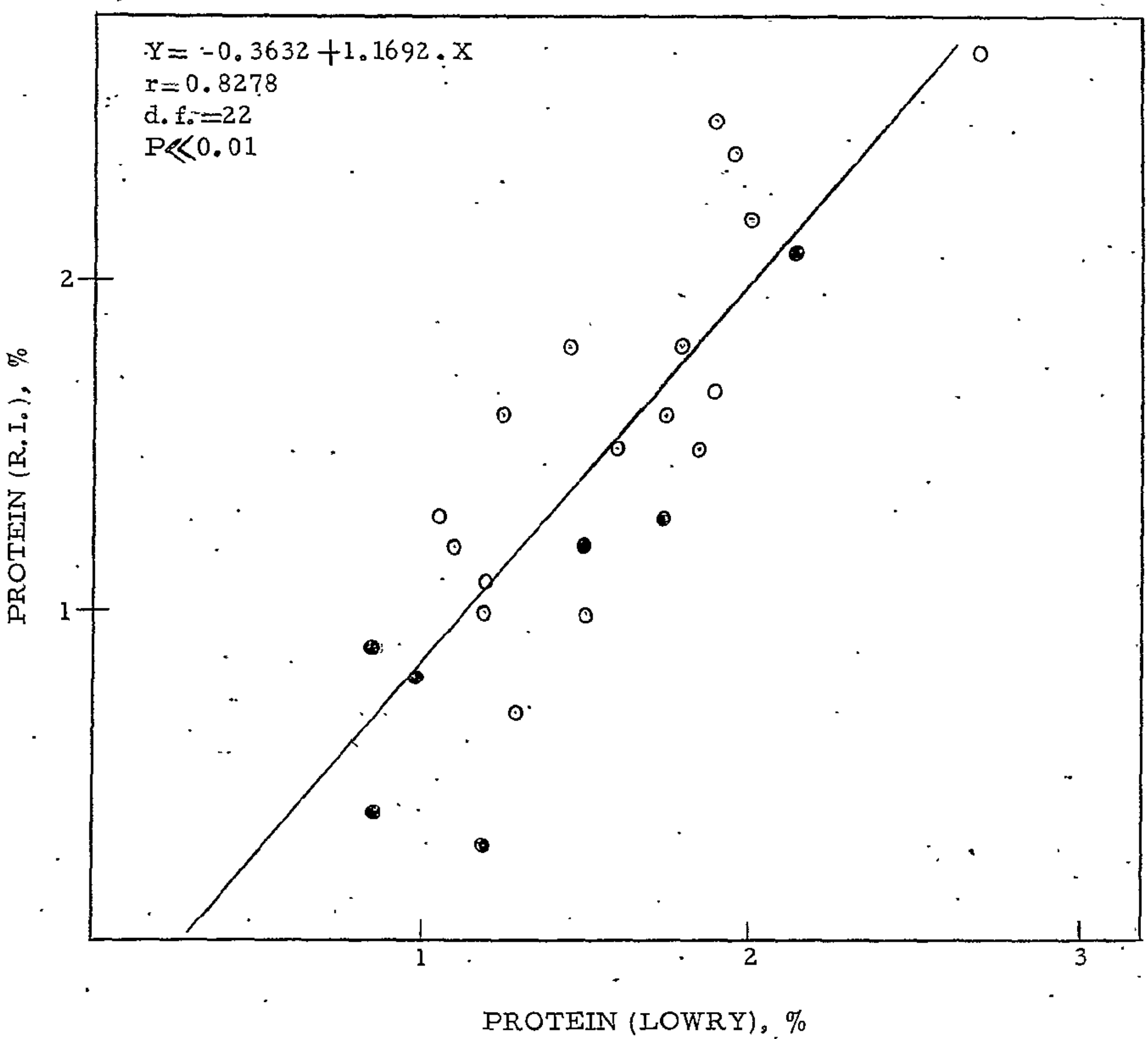
It was also recognized that analytical methods suitable for evaluating the protein content of potatoes are not precisely defined. Thus, despite the urgent need of providing material for early release to selected countries, it is imperative that research be initiated immediately, preferably by appropriate contract projects, to evaluate analytical techniques to separate, identify and quantify the various nitrogenous compounds found in potato tissue.

Promising techniques are being developed for processing potatoes in developing countries to provide nutritious products with good keeping qualities. Dr. A. Bacigalupo of the National Agrarian University has developed a number of products which have potential for village-type, labor-intensive processing. CIP does not have a staff nutritionist to evaluate potatoes and potato products by means of rat and human assays and to assess cultural food preferences in developing countries. Such value judgments are probably best obtained through linkage affiliations.

The quality of storage facilities has a direct influence in maintaining the nutritive status of potatoes. Dr. Max Milner has proposed the no-cost services of "VITA"- Volunteers for International Technical Assistance - to assist in innovative design of potato storages in developing countries. This group of Volunteers are professional engineers in the employment of General Electric in Schenectady, N.Y.

Specific project recommendations have been divided into those most suitably undertaken by CIP personnel and those most efficiently handled through linkage or contract arrangements.

Fig. 1 Relationship between Refractive Index difference and protein as determined by the Lowry method



A. RECOMMENDATIONS - CIP Projects

I. Broad-scale screening:

a) Prior to planting, soil is to be finely prepared and fertilizer is to be uniformly broadcast. Fertilizer type and rate are to be determined in conjunction with soil analyses. It is recommended that fertilizer amendments be standardized in a manner to minimize yield and quality variations from year to year.

b) Death of foliage, determined by weekly inspection, is to be considered as an indicator of maturity and is recommended as the time to harvest. Yield data are to be recorded.

c) Specific gravity is to be determined on clonal samples by weighing in air and in water. Graded saline solutions may be used as an auxiliary method for small tuber samples.

d) Tubers are to be sampled by the non-destructive removal of longitudinal wedges from apex to stem end to a depth to the center of a tuber. A blend of sub-samples of a clone, including tubers of various sizes, is suggested. Flesh color is to be assessed by reference to a color chart.

e) Fresh tuber samples are to be immobilized as soon as possible after harvest by low-temperature freezing (e.g. "dry ice") and then freeze dried. Fresh and dry weights of each sample are to be recorded. Samples will be powdered after drying and stored in a refrigerator.

Study period: Basically this is to be a continuing program throughout a five-year period. Commencing in 1974, 40 advanced clones with potential for Outreach distribution and grown in four environments, will be screened. Thus a total of approximately 1860 (4 x 40 + 200 + 1500) clones will be screened in 1974. In 1975 and 1976 selected clones from 1974 will be screened again along with additional clones from the germ plasm collection to give a quota of approximately 3000 clones in each year. A review of progress will be made annually, with a more thorough overall review in 1976.

Co-ordinators: Dr. R. Lüscher and Dr. P.R. Rowe

II. Quality Screening Sequence:

a) Nitrogen determinations by micro-Kjeldahl x 6.25 are to be made on each sample of freeze-dried tuber powder. The efficiency of extraction of soluble, non-protein nitrogen by acidified ethanol as a pre-treatment before Kjeldahl determinations is to be evaluated (Appendix I).

b) Relative Nutritive Value is to be determined. RNV is equal to Kjeldahl N x 6.25 digestible protein x biological value of the amino acids. It is to be determined

following microbiological assays with Streptococcus zymogenes and/or Tetrahymena pyriformis (Appendix II and III).

Dry matter yield is to be expressed in kgs./hectare.

Study Period: As per Recommendations - CIP Projects, Section 1.

Co-ordinator: Dr. R. Lüscher

III. Specific evaluation of protein quality:

a) It is recommended that selection and breeding of clones of high methionine content be given priority over increase of protein content. Initially a biological assay of methionine is preferred. Analysis of specific amino acids in tubers by Amino Acid Analyzer is recommended in specifically selected clones. Key amino acids to be evaluated are methionine, cystine and possibly proline. Limited data from selected families show that methionine is not highly correlated with protein content ($r = .69$). Proline is correlated ($r = .84$) with protein and would be one amino acid of choice for screening when suitable rapid quantitative methods are available for its determination.

It is recommended that the Analyzer presently available in La Molina be repaired and used for this purpose.

(See Appendix III regarding cystine).

Study Period: Methionine and cystine content to be routinely assessed by microbiological assay commencing in 1974. Progress to be evaluated annually with detailed review in 1976. Amino acid analysis to be considered in 1976.

Co-ordinators: Dr. R. Lüscher, Dr. K. Sayre, Dr. W. Roca

b) It is recommended that selected parents, or advanced clones prior to release, be assayed for general glyco-alkaloid content.

(There are no rapid methods presently available to assay glyco-alkaloids. A new method which measures the nitrogen present, rather than double bonds, should be forthcoming in the near future according to Dr. E.A. Talley). The following background references from Chemical Abstracts are pertinent: 37 4087 (1943), 38 40547 (1944), 55 22351 b and h (1961), 59 1709 g (1963) - describes a very useful ThC system, 60 15943 d (1964), 72 87188 (1970), 77 149672 (1972), 77 149774 (1972).

Study period: Evaluation of methods should commence in 1974. Routine evaluation of selected materials should continue at least until 1976 and progress and the need for continuation assessed.

Co-ordinator: Dr. K. Sayre

B. RECOMMENDATIONS - Contract Projects

Priority 1

a) It is recommended that methods of extracting and determining soluble tuber protein be investigated. The following techniques are to be examined and compared:

(i) Extraction of freeze-dried powder with 80% ethanol, 10% TCA, and 1% picric acid, as well as other concentrations of these solutions;

(ii) Dialysis in running tap water as per Fitzpatrick et al (Am. Potato J. 46: 273-286. 1969).

(iii) Evaluation of technique of expressing fresh juice as well as reconstituted freeze-dried powder and determining soluble protein by refractometer.

Study period: Two years duration commencing in 1974.

b) Rat bio-assays to assess protein quality relative to microbiological evaluations are recommended. It is proposed that some comparative tests to be made as soon as possible in order to verify relative nutritional ratings determined with S. zymogenes. It is recommended that 6 - 10 replicate rats be used in each trial.

Study period: Commence in late 1974 or early 1975 and continue for 4 or 5 trials.

Priority 2

a) Assessment of procedures to evaluate such glyco-alkaloids as alpha- and beta-chaconine, alpha-solanine, demissine, leptines and solamarines as well as phytate.

b) Assessment of vitamin C loss during storage, relative to varieties; influence of freeze-drying on vitamin C loss during storage.

The same contract project may also be concerned with rapid techniques for vitamin A assessment.

c) Progress would be more rapid if basic genetic information is available in order to effectively breed for desirable traits within Solanum. To establish linkage groups or chromosome maps reasonably efficient phenotypes reflecting specific genotypes need to be used. Biochemical gene markers in conjunction with trisomes would be an

example of a fairly rapid system of gene mapping. Potato is one of the major food crops which lacks essential genetic information required in any breeding program.

d) Inhibitor proteins may account for up to 10% of the soluble protein in tubers. The uniqueness of this group of proteins would make them very suitable for specific inheritance studies.

One basic question is: Do selections high in protein contain increased amounts of these inhibitors? The inhibitor proteins would be of great value in studies of protein synthesis since they can be readily identified.

C. RECOMMENDATIONS - Fundamental Research

a) The panel recognizes the importance of fundamental research as an underpinning of applied research and in particular of the contemplated attempts of creating high protein and high methionine potatoes. It therefore recommends that the Center actively encourages and endorses research activities in the following two areas as considered essential to success of its mission:

b) Cytogenetic and biochemical investigations with the aim of identifying gene markers and the establishment of a chromosome map of the potato.

c) Biochemical investigations on the nature of storage proteins of the potato, the factors that influence their production and deposition, and the biological function of the individual constituents.

APPENDIX I

PROCEDURES FOR TOTAL PROTEIN ESTIMATION IN POTATO TUBERS BY KJELDAHL TECHNIQUE

P.H. Li

I. Sample Preparation:

1. Wash tubers, weigh, and store in the cold storage room or refrigerator if not immediately for further treatment.

2. Remove longitudinal tuber wedge(s), weigh, and freeze immediately prior to freeze-drying.

3. Determine the dry weight after freeze drying.

4. Grind into 60 mesh size powder, and store in a freezer until analysis.

II. Pretreatment of sample:

Data collected from CIP's samples indicate that percentage of non-protein nitrogen can be varied from 35 to 63%. Removal of non-protein nitrogen is, therefore a necesary step in order to obtain a meaningful estimation of total protein by Kjeldahl technique in potato tuber.

1. Weigh exactly 1 gram of dry-powder into a 100 ml of Erlenmeyer flask, add 50 ml of 80% alcohol, and stop with a rubber stopper.

2. Shake the sample on a Forma Model 4537 shaker for at least 25 minutes at its highest speed.

3. While shaking, prepare an appropriate number of 150 ml of beakers for filtration with weighted filter paper.

4. Quantitatively transfer the slurry onto the filter paper. Wash the glass-ware, and then wash the residue with an appropriate amount of 80% alcohol until the filtrate in about 100 ml of volume.

5. Dry the residue with the weighed filter paper in an oven at 70°C for 24 hr. and weigh the total dry wt. of residue after drying.

6. Weigh an exact 100 mg residue for Kjeldahl N determination - Total protein nitrogen.

7. Convert the total protein nitrogen from residue to the dry weight of sample basis. Time the protein factor - Total true protein content.

III. Kjeldahl Determination:

1. Digestion:

a) Weigh exactly 100 mg or more of sample, and add 100 mg of catalyzer (Selenium mixture) into a Kjeldahl flask.

b) Add 2 ml of the digestive solution (H_2SO_4), and digest on the heater. Digestion will last about 30-40 min.

2. Distillation:

a) Add 20 ml of the "Indicator-Reagent" (Boric acid plus indicator) into a 50 ml Erlenmeyer flask, and place it under the exit of the distillating apparatus.

b) Quickly pour the digested solution into the upper container of the distillator, rinse Kjeldahl flask with distilled water and pour into the same container.

c) Open the stopcock and let the solution drain into the lower container of the distillator drop by drop.

d) Close the stopcock after all the solution has been transferred into the container and then add an appropriate amount of NaOH to the container.

e) Open the stockcock again and let solution mix slowly with digested solution; as soon as mixture turns violet, the stopcock should be closed immediately.

f) The above mixture will be distilled to allow the NH_3 to be absorbed in the Indicator-Reagent. Notice changing color (greenish). Wait 3 more minutes to allow all of the NH_3 to be completely absorbed.

3. Titration:

a) Remove Erlenmeyer flask and titrate with 0.1 N H_2SO_4 until to the end point (violet color).

b) Record ml of H_2SO_4 used for titration.

4. Calculation:

Use reference from general chemistry for N calculation after titration.

5. Reagents

a) H_2SO_4-K_2SO_4

1) Dissolve 25 g. potassium sulfate in a portion of concentrated H_2SO_4.

2) Prepare a saturated cupric sulfate solution. Remove 25 ml of $CuSO_4$ solution and add into 1).

3) Add 10 g. of Mercuric oxide yellow to 1).

4) Make to 1000 ml with con. H_2SO_4.

b) NaOH - 1000 g. of NaOH in 1000 ml of distilled water (with care) and then add 1 g. of phenolphthalein

c) Indicator Reagent:

1) Dissolve 100 mg methylene blue in about 20 ml of 95% EtOH.

2) Dissolve 180 mg of methyl red in about 20 ml of 95% EtOH.

3) Mix 1) and 2) and then make to 1000 ml with 95% EtOH.

4) Take 1 ml of the solution from 3) and mix with 1000 ml of 20% boric acid. (20 g. of boric acid plus 100 ml of H_2O).

APPENDIX II

MICROBIOLOGICAL BIO-ASSAY TO MEASURE "RELATIVE NUTRITIVE VALUE" AND "AVAILABLE" METHIONINE IN POTATOES

R. Lüscher

Summarized, Streptococcus zymogenes needs broadly the same amino acids as the growing rat. It is powerfully proteolytic and grows quickly with an adequate intact protein as the main source of nitrogen. Although lysine and serine are not indispensable, the absence of these in the growth medium restricts growth severely. Cystine "spares" methionine, in the sense that omission of cystine from the test medium increases the requirement for methionine by about 15%.

Streptococcus zymogenes has successfully been used to provide an estimation of protein quality. For 16 different food proteins, growth of S. zymogenes (=Relative Nutritive Value with reference to casein) correlated highly (r = 0.9) with the net protein utilization (NPU) values determined with the rat. With another set of 17 whale-meat meals, fish meals and meat, a similar correlation between growth of S. zymogenes and NPU values determined on rats was calculated (r = 0.81). Net protein utilization is equal to biological value (BV) X digestibility of the protein divided by 100. The fact that growth of S. zymogenes correlates with NPU values suggests that a bio-assay, with this proteolytic bacterium, can give an estimation for both BV and digestibility of the potato protein. "Available" methionine assayed with S. zymogenes agrees very well with chick results (r = 0.97). When heat damaged whale-meat meals were fed to rats and analyzed for total and "available" methionine, the Net Protein Utilization (NPU) values of the rat correlated r = 0.57 with total methionine (determined after acid hydrolysis) and as much as r = 0.92 with "available" methionine determined with S. zymogenes and enzymatic digestion. It is obvious from these results that the method involving S. zymogenes and enzymatic digestion is capable of measuring the biological "availability" of methionine in foodstuffs.

I. Method of Analysis:

1. Samples containing 50 mg of crude protein (N x 6.25) are weighed out into 100 ml bottles and suspended in 20 ml citrate cyanide buffer.

2. PH is adjusted to 7.2, the bottles are placed into a water bath at 55°C. Two ml of 4% (W/V) crude papain are added and incubated for 3 hours.

3. The samples are filtered through a Whatman N° 4 filter paper to remove starch, the pH adjusted to 7.2 and the volume is made up to 100 ml.

4. Two ml of the digests are added to each of 4 test tubes. To two test tubes, a medium containing vitamins, glucose salts, bases and all amino acids with the exception of methionine is added ("available" methionine).

5. To the two other test tubes the same medium but with the omission of the amino acids, is added (relative nutritive value).

6. After sterilization 1 drop of an actively growing culture of S. zymogene is added to each test tube, including the methionine and casein standards.

7. When the incubation is finished (40 h) the optical density of each test tube is measured at 580 nm with the aid of a flow through cell.

II. Bio-assays with Bacteria are Advantageous Because:

1. Less than 1 g of dry matter is required.

2. The assay takes just 2 days.
Rat assays need several thousand times more dry matter and last 2-4 weeks.

3. Only a moderate investment in laboratory equipment is necessary.

4. Bacterial assays can well be adapted for routine analysis of a large number of samples.

APPENDIX III

AMINO ACID ASSAY USING THE PROTOZOON TETRAHYMENA PYRIFORMIS W

R. Lüscher

Tetrahymena pyriformis W. is, as a protozoan, a more highly sophisticated micro-organism than Streptococcus zymogenes.

T. pyriformis W. requires absolutely: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine, the ten amino acids generally regarded as essential for the growth of higher animals.

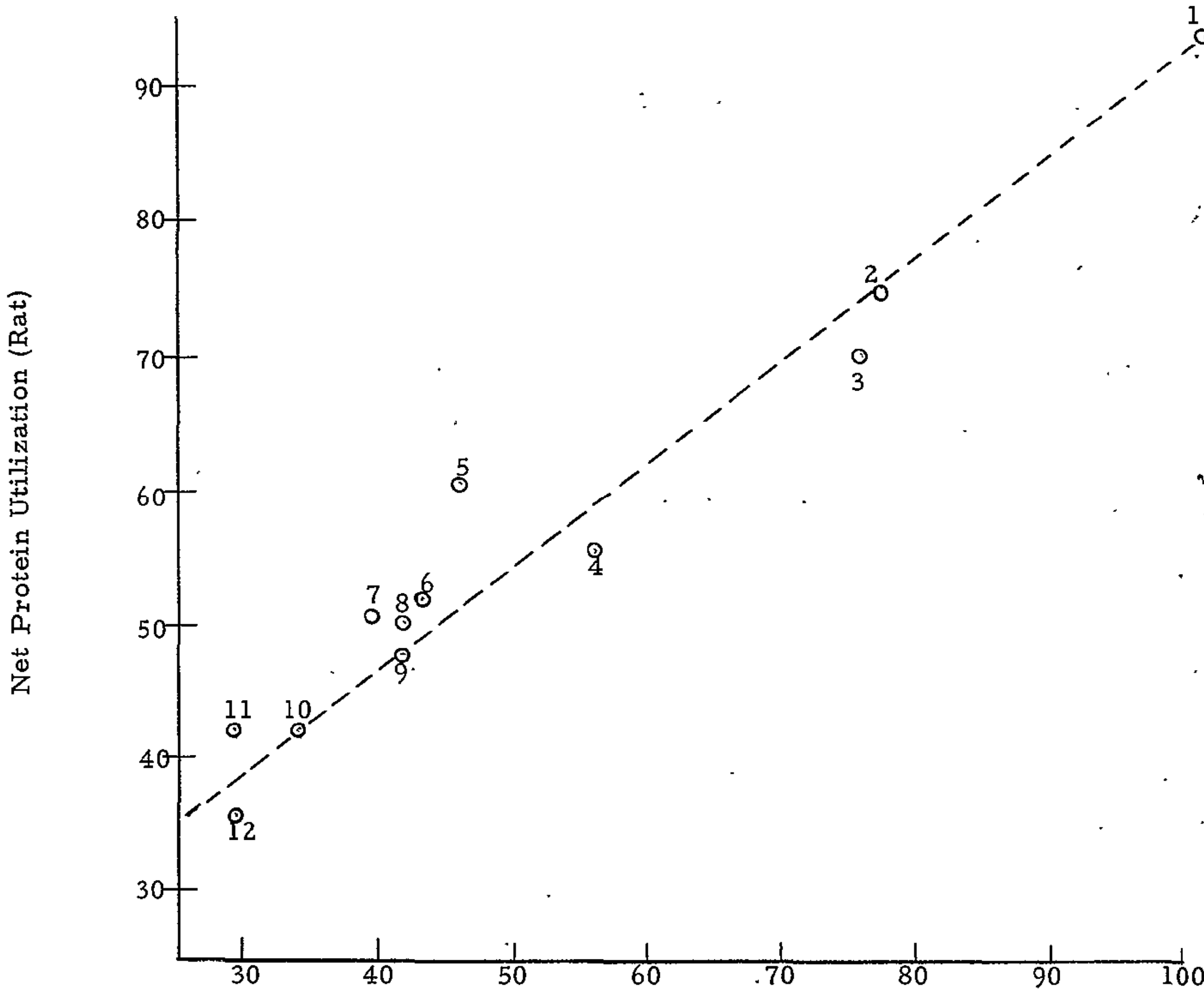
I. Procedure:

1. A sample containing 3 mg crude protein (Kjeldahl N x 6.25) is weighed into a 125 ml Erlenmeyer flask. Then various solutions containing glucose, vitamins, purines, pyrimidines and salts are added into the Erlenmeyer flask.

2. Sterilization of the flasks is followed by adding 3 drops of an actively growing T. pyriformis culture to each flask.

3. After an incubation time of 4 days at 25°C, growth of the protozoan is measured by counting a 1 ml sample in a haemocytometer under the microscope. The total number of organisms/ml of medium is directly proportional to the NPU value of the protein.

Fig. 2 Comparison of protein nutritive values obtained with the rat and with T. pyriformis W



Relative nutritive value of T. pyriformis W with reference to egg protein 100

1. Whole egg powder
2. Skim milk powder
3. Casein
4. Soybean (whole)
5. Copra oil meal
6. Bengal gram dhal
7. Groundnut oil meal
8. Hope gram (whole)
9. Green gram dhal
10. Peas, black variety
11. Aconite beans
12. Lentil dhal

APPENDIX IV

CYSTINE ANALYSES IN POTATOES

R. Lüscher

Dietary cystine reduces the methionine requirement in mammals. It is therefore important that methionine and cystine analyses are performed. The traditional analyses of cystine involving acid hydrolysis is not suitable for potato samples, because of the destruction of cystine due to the presence of large amounts of carbohydrates. However there are three alternative methods available worthy to evaluate for suitability:

I. The use of a proteolytic strain of Clostridium perfringens. This strain was used to assay for cystine before the automatic ion-exchange chromatograph was introduced. The fact that it is vigorously proteolytic opens the possibility, that it could be grown on the enzymatic digest already prepared for the analysis of "available" methionine. Thus we would measure "available" cystine with this procedure. Under the conditions of the experiments there is no formation of a toxin (lecithinase) or any of the other known toxins or exoenzymes (hyaluronidase, 0 toxin, gelatinase) in this medium. However, this organism does not lose its ability to form toxins when grown under conditions suitable for toxin production.

II. Estimation of the sulfur amino acids by a short ion-exchange column method. In this method the samples are first oxidized with performic acid and then hydrolysed. Cysteic acid, methionine sulfone and lysine can be eluted with a buffer. If a fraction collector, a column and a spectraphotometer are available, this procedure should not cause problems. Pertinent references in Chemical Abstracts include: 67 72481, 72486 (1967), 71 681 (1969), 72 28806, 51612 (1970), 73 13176, 33923, 51613 (1970), 74 38993 (1971), 75 137384 (1971), 76 1500, 1501, 1505, 12861, 31983, 31984, 57807, 57813 (1972), 77 18461, 45080, 137043 (1972), 78 68909 (1973), 79 50577, 63355, 63356, 89047 (1973).

III. Method of N. Taniguchi

This method is simple and accurate and has two steps: (1) conversion to zinc sulfide from cysteine or/and cystine in protein by treatment of a pH 9.5, 0.6% zinc hydroxide suspension at 100°C for 48-96 hours. (2) Colorimetric determination of hydrogen sulfide obtained by acidification of zinc sulfide. Methionine and cystine synthesis are interrelated. It is therefore important that clones high in methionine are analysed for cystine, too, in order to avoid clones in which a higher methionine value is achieved at the cost of cystine.

APPENDIX V

"NUTRITIVE VALUE OF POTATOES, A REVIEW"

Ora Smith

I. PROTEIN - INCREASING QUANTITY AND QUALITY

The principal objective of research in this field is to increase the nutritional value of potatoes by increasing the amount and quality of potato proteins. Interest in the proteins of the potato has increased markedly recently because of the high biological value of potato protein and its potentially high yields of protein per unit area of land. The possibilities of increasing the protein production of potatoes by plant breeding and growing techniques have been widely studied (Fitzpatrick et al 1969; Talley et al 1970; Mica 1971; Westerlind 1971; Varis 1973 and many others). Attention has been paid to proteins in the potato also because of the deleterious effects they often have on the quality of table potatoes and especially on some processed forms (Findlen 1960; Smith and Treadway 1960; Fitzpatrick and Porter 1966; Varis 1970 and others).

The carbohydrate to protein ratio in potatoes is relatively high. It has been shown, however, that the potato can serve as the sole source of nitrogen for humans. Kon and Klein (1928) showed that a man and woman were maintained in good health for 167 days on such a diet by the daily consumption of 1680 and 1120 grams of potatoes, respectively. By increasing the protein content of the potato, it would be greatly improved as a food in many areas of the world.

Chick and Slack (1949) also showed that, unlike many foods, the non-protein nitrogen of the potato has considerable nutritional value, as it consists largely of free amino acids a factor which complements the potato protein nutritionally. The high starch to protein ratio requires a high caloric intake to furnish the daily requirement of protein. More protein per calorie could be supplied if the protein content were increased.

According to Kofranyi and Jekot (1965) the nutritional value of potato protein is as good as or better than whole egg, and better than beef, tuna, whole milk, wheat flour, corn, rice, soybean and kidney bean protein. A mixture of 35 percent whole egg and 65 percent potato gave the lowest nitrogen intake for maintaining a nitrogen balance ever found by these authors.

The nutritional or biological value of protein in potatoes is rather high. Biological value of 258 German samples of potatoes ranged from 61.08 to 88.92 (Schuphan 1959). Potato protein contains substantially more of all the essential amino acids except histidine than that of whole wheat. The amount of lysine in potatoes is similar to that in a typical animal protein (Hughes 1958). Choudhuri et al (1963) found that the potato protein content per 100 gm. of raw, cooked, baked, fried and canned potato on a fresh weight basis is 1.96, 1.93, 2.43, 3.73 and 1.6 percent respectively.

In rat feeding experiments Chang and Avery (1969) found that the nutritive value of potato protein was superior to that of rice. Weight gains and protein efficiency ratios were higher in those rats fed the potato diet. The fat concentration in the liver also was significantly lower in the animals fed the potato diet.

MacGillivray and Bosely (1962) claim that potatoes produce more essential amino acids per acre than milk, oats, beef or lamb.

It is well known that the level of soil fertility and nutrient availability affect the protein content of potatoes. Commercial varieties of potatoes grown under the same environmental conditions also vary in protein content. The potential of breeding potato varieties of higher protein content than those presently available is great.

An increase in the dry matter of a tuber is accompanied by a comparable increase in the starch content. The non-starch solids are relatively constant over a wide range of total solids variation. Burton (1948) and others have reported this constant to be about 6 percent. Houghland (1966), however, showed that this figure is not constant between varieties varying considerably in dry matter and starch content.

A. Breeding

Since total nitrogen content of tubers ranges from 1.4-2.8 percent of the dry weight and protein nitrogen content rarely exceeds one half of this value, breeding for an increase in dry matter content probably would not be very successful in increasing the protein content of potatoes. Peare and Thompson (1973) found that with 16 cultivars grown in 10 states percent protein was inversely related to the percent of total solids in the tubers. The highest total nitrogen, soluble N and insoluble N, content on a dry basis is found in potatoes with the lowest solids (Talley et al 1961; Talley et al 1964; Talley and Porter 1970; Talley et al 1970).

The nutritional value of a lot of potatoes as measured by total, soluble and insoluble N is the same from those of high, medium and low solids content (Talley et al 1961). There is an inverse relationship between solids content and nitrogen values (total, soluble and insoluble nitrogen) when calculated on a moisture free basis (Fitzpatrick et al 1964). The relationship of insoluble nitrogen to total nitrogen remains fairly constant, regardless of the solids content of the potatoes with ratios varying from 0.39 to 0.43.

The content of individual amino acids on the fresh weight basis also is essentially constant with respect to specific gravity of the potatoes. On the dry basis, however, significant differences in most instances were found between levels of specific gravity groups. Proline content increases with length of storage and especially when the tubers sprout. The changes in alanine are in almost the reverse order (Talley et al 1964).

Fitzpatrick et al (1969) report that the percentage of total nitrogen on a dry weight basis for 83 seedling samples and selections grown in Maine and Idaho, was higher in low solids potatoes than in those of high solids. Calculation for total solids vs protein nitrogen,

respectively indicate a direct correlation with the total nitrogen data. On both a fresh and a dry basis, an increase in protein nitrogen results in an increase in the ratio of protein to non-protein nitrogen. The authors state that since a low ratio of starch to protein, or a high energy percentage, indicates a high protein content relative to the starch present, the aim of any breeding experiments should be toward a low ratio and, when combined with a relatively high total solids, a nutritious and productive variety should result. They state further that in samples such as those with which they worked, and probably others, rests a potential for the development of a potato variety containing increased nitrogenous constituents, both in absolute amounts and in amounts relative to the total solids, or better, to the starch content. The goal of future work is to ascertain how these differences are transmitted to the progeny. The present work indicates that there are varietal differences, and later work must determine their inheritance pattern. The stability of the protein content in high protein selections must be tested in different environments. This should be followed by an examination of the high protein selections to determine whether the presently desirable attributes needed in cooking, processing, etc., will be retained.

Sanford et al (1971) reported on the effectiveness of selection for tuber total nitrogen in a tetraploid breeding population. Offspring total N ranged from 0.20-0.50 percent (crude protein percent of 1.25-3.13) in 1968 and from 0.20-0.40 percent that within the tested population, genetic variability exists for total N content of sufficient magnitude to allow improvement by selection.

Desborough and Weiser (1972) determined the soluble and total protein relative to tuber protein inheritance in six diploid and tetraploid Phureja-haploid Tuberosum families. The relative amounts of tuber protein were increased substantially in the first generation of selection. Total protein and soluble protein appeared to be directly influenced by ploidy level and growing location. Their data indicate that the diploid selections have as much or more potential than the tetraploids for a selection program to increase protein. The authors plan an expanded survey of diverse germ plasm in an attempt to find other sources of high tuber protein. Studies of the heritability of tuber protein are in progress. They also plan to compare the amino acids in tubers high in protein, specifically those that are limiting in human nutrition. Their future studies also will consider the effects of increased protein on various cooking and flavor qualities.

Kaldy (1971) and Kaldy and Markakis (1972) determined 18 amino acids quantitatively in Russet Burbank and five clonal selections. Protein scores in the sulfur-containing amino acids for Russet Burbank and the five clones were 73, 78, 60, 62, 73 and 68 respectively. Methionine was the limiting amino acid in all samples.

Kaldy et al (1972) measured the protein content of 21 varieties by the Kjeldahl N determination and by the binding of the dye Orange G. They found a linear relation between the N content and bound dye. The correlation coefficient was +0.9827.

B. Seasonal variations

Yield of protein may vary from season to season depending upon weather conditions. Although Talley et al (1970) found irregular variation in tuber protein content due to weather variations between years, tuber yield apparently has a larger effect on the total protein yield than does the protein content of our present varieties.

C. Soil type

Soil type also influences total protein yield. On peat soils (Varis 1973) tuber yields were high and tuber protein content also was high apparently because of the higher content of nitrogen in the soil.

D. Maturity of potatoes when harvested

Early harvesting results in reduced tuber yield and lower protein content and thus lower protein yield (Varis 1973). Protein continues to move into tubers to the end of the growing season, thus the more mature they are, the higher the protein content.

E. Nutrition of the potato

Fertilizer treatments affect both tuber and protein yields as well as protein content. Varis (1973) obtained lowest tuber yields, lowest protein content and lowest protein yields from unfertilized areas and from those fertilized with farmyard manure. The presence of a sufficient amount of N in the soil seems to be necessary to obtain large protein yields. High N application (150 kg/ha) greatly increased protein content and thus the protein yield. Similar results have been obtained by Swiniarski and Ladenberger (1970) in Poland; Westerlind (1971) in Finland and others.

The application of KCl as the source of potassium compared with K_2SO_4 reduced the protein content and through that, the protein yield as well (Varis 1973). By increasing the application of N from 36 to 336 lbs. per acre crude protein content of potato was increased from 9.5 to 12.9 percent and true protein content from 3.8 to 5.4 percent (Wilcox and Hoff 1970). The amino acid pool in the tubers almost doubled by such increases in N applied (Hoff et al 1971). Increases in individual amino acids ranged from none (tyrosine) to 2.7 fold (glutamic acid + glutamine). Lysine and methionine increased with increasing N applied but the relative proportions of lysine remained unchanged and methionine decreased.

With N applications up to 184 lbs. per acre the essential amino acid content slightly increases; more noticeably with leucine, isoleucine and arginine, less with lysine and phenylalanine, while histidine was only slightly affected (Schuphan 1959).

In Poland Loginow and Klupczynski (1969) found that increasing amounts of N applied resulted in a proportional increase in protein percentage. Increases in K fertilization did not affect percentage of protein in the tubers.

Results of a number of experiments in Russia show that increasing amounts of complete fertilizers increased the protein content of the tubers (Tikhonow and Avdeev 1970); long term fertilization with N-P-K increased the level of protein as well as essential amino acids with 75 to 90 percent of the essential amino acids being bound to the proteins (Tikhonov and Bychkov 1969A); the content of each individual essential amino acid in tubers was increased by fertilization. Yield of protein per hectare was increased three-fold by N-P-K plus manure over the unfertilized but the biological value of the total protein in the potato was lower (Tikhonov and Bychkov 1969B); sulfate form of potash in the fertilizer produced more protein and improved the organoleptic rating compared with those grown with muriate form of potash (Zhuk and Gupalo 1970). Chelpanova (1972) obtained most marked increases in potato yield and of total N and protein N in the tubers from NH_4NO_3 and urea forms of N. Highest protein content tubers resulted from N forms of ammonia water, $(NH_4)_2SO_4$ and NH_4NO_3.

In Sweden (Svensson 1969) application per hectare of 200 kg of N in the form of $(NH_4)_2SO_4$ increased the content of N by almost one percent of the dry matter of the tubers above the application of 50 kg N per hectare.

Mica (1971) reported that in Czechoslovakia increased fertilization with N-P-K slightly reduced the total amino acid content. A level of 100 kg N/ha. gave the highest protein content. Lysine and leucine were the principal amino acids.

In Hungary a good N supply from NH_4NO_3 increased the quality and the levels of total protein and non-protein N. Of the amino acids, glutamine, asparagine and arginine responded most to the N fertilization (Filep and Bukai 1969). In Bulgaria Dimitrov (1969) reported that N fertilization increased protein content of the tubers; in India Hukkeri (1968) found that N and P applications increased the percent crude protein in tubers and Coutrez-Geerinck (1970) in Belgium reported that in general the growing medium highest in N resulted in the highest amount of each amino acid in the tubers.

F. Photoperiod

Significant differences between day lengths in crude protein content of tubers both on a dry matter basis and a fresh weight basis were found with higher percentages under a 14-hour day than under continuous light (Umaerus 1970).

G. Effect of 2,4-D application

Spray application of 2,4-D to potato plants late in the growing season increased the protein content of Red McClure tubers grown in Colorado (Payne et al 1953).

H. Effect of application of sprout inhibitor to plants

Maleic hydrazide spray increased protein content of tubers immediately after harvest but after 60 days storage at 40°F it was lower than those untreated (Yasuda et al 1956); Rakitin and Strel'nikova (1970) report a decrease in protein nitrogen resulting from maleic hydrazide application.

I. Effect of application of herbicides

Simazine increased the crude and true protein content of potatoes (Mazur and Kawecka 1969).

J. Effect of gamma irradiation

Eight krads of gamma radiation had no significant effect on the digestibility or biological value of potato protein (Varela and Urbano 1971). Free amino acids increased gradually in proportion to the radiation dose up to 30 megarads (Boffi, Ferrari and Ferrara 1969). Irradiation of tubers with 7,000 - 30,000 rad which were then stored 15 days at room temperature increased by 30-50 percent the contents of free aspartic acid, proline, and aliphatic amino acids. Free glutamic acid and basic amino acids decreased slightly (Fujimaki, Tajima and Matsumoto 1968). Twenty-four hours after irradiation at doses up to 500 krad there was an increase in aspartic acid, asparagine, threonine, serine, alanine, leucine, isoleucine, lysine and arginine decreased (Kodenchery and Nair 1972).

K. Effect of other factors

Content of protein increased in virus X inoculated plant tubers (Chegolina 1969). Bordeaux mixture or copper chloroxide sprayed on plants at the beginning of flowering and 10 days later increased the protein content of tubers (Gladilovich and Gudkova 1971).

The amount of amino acids was higher in a variety resistant to the attack of *Phytophthora infestans* (Merkur variety) compared to the less resistant variety (Bintje). Glutamic and aspartic acids comprised 22 percent of total amino acids in Bintje and 21 percent in Merkur before infection. Three days after infection, glutamic and aspartic acids comprised 7 percent of total amino acids in Bintje and 12 percent in Merkur. Serine and arginine increased after infection, especially in Bintje, where they increased from 11 percent of total amino acids to 29 percent (Olteanu and Brad 1969).

L. Methods and techniques used for determining protein and amino acids

Methods of preparing and analyzing potato samples for free amino acids are described on pages 357-361 of Talley et al 1964.

Kaldy et al (1972) measured the protein content of 21 varieties of potatoes grown under similar conditions by Kjeldahl N determination and by the binding of the dye Orange G. Desborough and Peloquin (1969) separated tuber proteins by acid gel disc electrophoresis. Peare and Thompson (1973) determined protein quality of a potato flour protein concentrate by rat feeding data and by microbiological assay using *Streptococcus zymogenes*.

Nutritive value per unit of land area and comparative nutritive values

Burton (1966) presents data for comparison of the nutritive values of potatoes to that of bread. In every case except that of calcium the values are based on the amounts of the

various substances actually absorbed. The values for calcium probably are too high as some of it probably is unavailable both in potatoes and bread.

As a source of calories potatoes are, weight for weight, less than 1/3 as valuable as bread. However, if the potatoes are French fried or chipped they would be equivalent to or higher in calories than the same weight of bread. The boiled, steamed and baked potatoes are about as good a source of nitrogen as is the bread. Neither bread nor potatoes are a good source of vitamin A. Thiamine, riboflavin and niacin in boiled, steamed and baked potatoes are in amounts comparable to those in white bread, but much lower than those in whole meal bread. Bread contains no vitamin C, whereas the potato is a valuable source of this vitamin. Potatoes on the whole are inferior to bread as sources of phosphorus and calcium, but their iron content may be comparable or superior even to that of wholemeal bread.

Burton (1966) has compored the relative amounts of bread and potatoes which might be expected on the average to be produced per hectare in northern Europe. Four metric tons of wheat would result in about 4.8 tons of white bread (72% extraction flour) or 6.5 tons of wholemeal bread (92% extraction flour). Twenty-five tons of potatoes would give about 20 tons of peeled product. The comparative caloric values of the food produced from a hectare of land would thus be: potatoes 100; wholemeal bread 104; white bread 81. Twenty-five years ago potatoes outstripped wheat in efficiency of food production per area of land in that same area. In recent years wheat yields have increased relatively more than have those of potatoes.

MacGillivray and Bosley (1962) using average yield data of crops grown in the 1940's report that potatoes produced about five pounds per acre of the eight essential amino acids. This figure was about the same as those for wheat flour, corn meal, brown rice and carrots.

Thompson (1973) has presented more up-to-date data of yields and compared the net protein production of corn, wheat and potatoes in the United States. Potatoes produce a greater amount of net protein per hectare than does corn or wheat. He also points out that Borgstrom calculated one hectare of potatoes can supply the protein requirement for 9.5 people, while wheat can supply protein for only 6.3 persons.

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II. POTATO QUALITY OTHER THAN PROTEIN

Specific gravity of raw potatoes has long been used as a measure of the texture of cooked potatoes. More recently specific gravity has been utilized as a forecast of the quality of processed forms of potatoes and also to a great degree the yields of the finished product. A very high correlation exists between specific gravity of raw potatoes, their total solids content and texture of the cooked potatoes. Although there are inherent inaccuracies of the specific gravity method of dry matter estimation, it is widely used because of the ease and rapidity of the determination and because no better method has yet been devised for large scale use.

It has been shown that tissue air space definitely influences specific gravity of individual samples. These variations could cause errors to as much as two percent of dry matter (Burton 1950). Other factors which may affect the relationship between specific gravity and texture of the cooked potatoes is the variable proportion of starch to other solids in the potatoes. Variations also may be caused by such factors as variety, growing conditions, areas of growth, internal composition of tubers, analytical techniques and perhaps others.

Fitzpatrick et al (1969) found that with 483 potato samples, representing breeding samples, five commercial varieties grown in six locations for two consecutive growing seasons and tubers grown in northeastern and north central sections of the U.S., the 95 percent confidence limits of the linear regression curve of specific gravity and total solids was $\pm$ 2.11. These results show that equating specific gravity with total solids has limitations. For example,

tubers with a specific gravity of 1.080 might range in total solids from 18 to 22 percent. The authors point out that the majority of points falling outside the confidence limits were from a set of samples (265 of a total of 483) whose total solids content was determined by a procedure considerably different from that used for the other 218 samples. The difference in technique was largely in the methods of drying the samples. Apparently there is no standard procedure for drying potatoes to determine their solids content.

Hundreds of papers from most areas of the world have been published showing the relationship between specific gravity of potatoes and texture of the cooked potatoes and in many instances also indicating the close relationship between specific gravity and yields of some forms of processed products.

A. Carbohydrates

The constituents of the potato about which most is known are the carbohydrates, which are comprised largely of starch.

Starch

Starch comprising from 65 to 80 percent of the dry weight of the potato tuber, is calorically the most important nutritional component. In the raw tuber starch is present as microscopic granules in the leucoplasts lining the interior of the walls of the cells of the parenchyma tissue. The granules are on the average about 100 microns by 60 microns. Small grain size has been associated with small tubers, dry growing season, immaturity, potassium deficiency, and prolonged post-harvest storage. Properties of potato starch are determined fundamentally by the size of the granules.

It has been demonstrated repeatedly that there is a close correlation among specific gravity, total solids and starch content. (Von Scheele et al (1937) found correlation coefficients between specific gravity and dry matter content = +0.937; between dry matter and starch = +0.956 and between specific gravity and starch content = +0.947). This close correlation is due to the fact that starch comprises a major proportion of the dry matter and that the percentage of non-starch solids in the fresh tuber is relatively constant, according to Burton (1966), around six percent. The method has obvious limitations due to differences in intercellular space, vacuolar content, etc. However, it provides a rapid method and often in commercial operations the only feasible method for making this important determination.

Some varieties inherently have higher starch contents than others. Factors which affect starch content of potatoes are fertilization, cultural conditions such as planting date, maturity, photoperiod, light intensity, soil moisture, spacing, soil and air temperatures, time of vine killing, presence of diseases, etc.

The relationship between starch content and texture of cooked potatoes has been investigated for about 75 years. It has been shown that there is a highly significant correlation between the starch content of the raw tuber and textural qualities such as mealiness, consistency, sloughing and sogginess. The properties of starch and the changes

which they undergo during cooking must be considered in studies to explain variations in texture.

During the cooking process water is taken up by the starch granule which then starts to swell. In the range of 147° to 160°F., the starch begins to gelatinize. In potatoes of high starch content the cells tend to round off and separate as a result of the swelling of the gelatinized starch, resulting in a mealy texture. In potatoes of low starch content the cells retain their original orientation with each other, they do not roundout and, therefore, result in a soggy texture. It is the amount of starch in the individual cell rather than the total amount of starch in the tuber that is related to the mechanism of cell separation.

Excessive cell separation, which quite often occurs in the cortical region of the tuber, results in sloughing.

Sugars - Potatoes may contain from zero to 10 percent sugar on the dry basis. Sugar content varies as to variety, degree of maturity, growing conditions, and storage temperature.

Potato breeders are intent on producing new varieties low in sugars, especially those to be used for processing.

The most important factor affecting sugar content of potatoes is the temperature to which they are subjected. At storage temperatures below 45-50°F., total and reducing sugars increase, the rate and extent of increase being greater the lower the temperature down to the freezing point.

The sugar content of potatoes is relatively unimportant except for those to be processed. Reducing sugar content of potatoes determines to a great extent the intensity of the browning reaction often resulting in excessive color development during processing and subsequent storage.

Non-starch polysaccharides

Relatively small quantities of the following occur in potatoes primarily in the cell walls and between cell walls of adjoining cells: (1) crude fiber, (2) cellulose, (3) hemicellulose, (4) pectic substances and (5) other polysaccharides. Some of these factors are related to texture of cooked and processed potatoes.

B. Lipids and organic acids

The average fat content of a potato is approximately 0.1 percent on a fresh weight basis, ranging from 0.02 to 0.2 percent. These small amounts of fat may be a factor in the oxidative deterioration of dehydrated potatoes and flour.

A number of organic acids normally occur in potatoes although they are not related to nutritive value.

C. Minerals

The potato is a good source of iron and magnesium as well as contributing some calcium, phosphorus, and most of the trace-minerals that are lacking in milk. Potatoes are among the richest foods in potassium, but it is not known to be a mineral which is deficient in most diets. Almost all of the iron in boiled potatoes is present in an available form (McCance and Widdowson 1942). The intake of iron guards our bodies against anemia. About 10 percent of the iron in potatoes is lost in various forms of cookery. A substantial amount of iron is in the peeling of baked potatoes. Peeling potatoes resulted in a loss of 10 percent of the iron in boiled potatoes.

Although potatoes contain only a small amount of calcium, they have been shown to have a beneficial effect on calcium metabolism because they contain little of the phosphorus compound known as phytin.

Potatoes are very low in sodium and, therefore, are excellent in the diet of those who attempt to reduce their blood pressure by limiting their intake of salt.

Potatoes are alkaline yielding foods in contrast to such foods as meat and eggs which yield an acid ash.

Magnesium has been given little attention in human nutrition, but it has become more important as research has shown that it will prevent and overcome the formation of stones in the bladder and the calcification of the soft tissues of the kidneys. It also is helpful in treating high blood pressure and difficulties with the heart. A typical person excretes about 200 mg of magnesium per day. To keep in balance this must be replaced and could be provided with about a half pound of potatoes if the remainder of the diet was low in this element. The human diets low in magnesium are those based largely upon milk or milk products because milk has only 12 mg. per 100 ml. (Halden 1956). It has only 1/5 to 1/10 as much magnesium as potatoes. Hence, milk and potatoes are excellent supplements since milk provides calcium and potatoes provide magnesium (McCay and Mc Cay 1967).

Vitamins in potatoes

Of the six vitamins included in the recommended daily dietary allowances of the Food and Nutrition Board of the National Research Council, potatoes contain substantial amounts of four, namely ascorbic acid or vitamin C, niacin, thiamine, and riboflavin. Of the four vitamins, potatoes furnish Vitamin C in greatest amount.

Vitamin C

Thousands of analyses of the vitamin C content of potatoes have been reported, the values ranging from 50 mg. in 100 gm. freshly harvested, immature potatoes to less than 10 mg. for potatoes stored for periods of many months.

The inorganic constituents of potatoes (extremes found)

	mg. per 100 gm. dry basis		ppm dry basis
P	43.0 - 605	Br	4.8 - 8.5
Ca	10 - 120	B	4.5 - 8.6
Mg	46 - 216	I	0.5 - 3.87
Na	0 - 332	Li	trace
K	1394 - 2825	As	0.35
Fe	3 - 18.5	Co	0.065
S	43 - 423	Ni	0.26
Cl	45 - 805	Mo	0.26
Zn	1.7 - 2.2		
Cu	0.6 - 2.8		
Si	5.1 - 17.3		
Mn	0.18 - 8.5		
Al	0.2 - 35.4		

From Lampitt and Goldenberg (1940).

In the United States potatoes contribute more vitamin C to the food supply than any other one food. One medium sized baked potato (100 gm) yields 20 mg. of vitamin C, which is 1/3 of the daily dietary allowance per man recommended by the Food and Nutrition Board of the National Research Council.

Variety, location, growing and storage conditions, degree of maturity, as well as methods of preparation for eating markedly affect the vitamin C content of potatoes.

Variety

Hyde (1962) found ascorbic acid content of various potato varieties was 19 to 29.1 mg. per 100 grams. The content of vitamin C is higher in potatoes of varieties of more intense yellow flesh color. Lampitt et al (1945) found that in a number of varieties grown in England, the ascorbic acid values ranged from 16 to 41 mg. per 100 gm. when analyzed the day after harvest. Reestman et al (1943) also reported varietal differences in ascorbic acid content of potatoes grown in Holland.

Location

It is not very clear as to the importance of location on the content of ascorbic acid in potatoes. Some differences which have been reported may have resulted from variation in factors other than that of location. Abramova (1961) reported that the amounts of ascorbic acid in a number of varieties grown in the Irkutsk region of the Soviet Union are higher than in those grown in the southern and western areas. In a study of eight varieties grown in various locations in New York with different conditions of fertilization, Karikka et al (1944) found no relationship of location to vitamin C content of potatoes.

Ascorbic acid content of potato tubers increased with an increase in altitude at which the potatoes were grown in Russia (Blagoveschenskii 1937).

Soils and fertilizer

The effects of soil in which potatoes are grown on the vitamin C content of potatoes also is not firmly established. Biletska (1961) claimed that tubers grown on peat soil contained less ascorbic acid than those grown on mineral soils. Julen (1944) reported potatoes grown on sandy soil contained more ascorbic acid than those grown on heavier soils. On the other hand, Smith and Paterson (1937) found ascorbic acid content was not related to soil type and Karikka et al (1944) reported no variation in vitamin C in potatoes grown in a number of soils in New York.

Fertilization apparently plays a minor role in determining ascorbic acid content of potatoes. Smith and Gillies (1940) report that fertilizer application had no significant effect on the content of ascorbic acid. The results of Karikka et al (1944) were similar except that they found that with no nitrogen application there was a decrease in ascorbic acid content.

Degree of maturity

Several investigators have reported that immature tubers contained more ascorbic acid than mature ones (Smith and Paterson 1937; Woods 1935; Zilva and Barker 1939). Volkov (1959) found maximum content of vitamin C in tubers of early potatoes on the 27th day after the beginning of tuber formation. On the other hand Namek and Moustafa (1953) report that ascorbic acid content increases in potatoes until the tubers mature. A gradual decline follows after the vines start to dry up. Enachescu (1960) states that at maturity, tubers contain 20-50 percent more ascorbic acid than immature tubers. Some of these apparent differences in results could be due to the degree of maturity at harvest, the length of time between harvest and analysis of the sample, soil and air temperature immediately preceding harvest, methods of analyzing the samples, etc.

Storage conditions

During storage, ascorbic acid content of tubers decreases. This change is related to both length of storage and storage temperature. That ascorbic acid decreases when freshly dug potatoes are stored at 50 to 59°F. has been shown by a number of workers. At lower temperatures ascorbic acid losses are even greater. At 41°F. ascorbic acid disappearance is greater than at 59° and at 32°F. the losses are more rapid than at 50°F. (Mayfield et al 1937; Rolf 1940; Karikka et al 1944; Murphy 1946). Olliver (1936), however, found slower rates of loss at 32° and 31° than at 50° or at room temperature.

Panalaks and Pelletier (1960) also found that tubers of Katahdin and Russet Burbank varieties stored at 68°F. were higher in ascorbic acid than those stored at 40°F. Russet Burbank tubers stored at 40° and then held for three weeks at 68°F. increased in ascorbic acid about 8-11 mg. per 100 gm. of tuber.

Ascorbic acid increases when potatoes, previously held at 50°F. or higher, are transferred to 32°, 34°, or 41°F. (Kelly and Somers 1949; Barker 1950).

Greatest loss of ascorbic acid occurred during the first four months storage and were about the same as at nine months storage.

Effect of irradiation

Results on effect of irradiation on ascorbic acid in potatoes are somewhat conflicting. In general, gamma irradiation of potatoes soon after harvest causes considerable loss in ascorbic acid while irradiation a month or more after harvest causes little loss. Gamma irradiation at a dosage of 15,000 rep. resulted in a decrease in ascorbic acid content below the untreated for the first seven months storage at 38°, 45°, and 50°F. and for four months at 60°F. Beyond seven months storage there was very little difference between treated and untreated tubers (Sereno et al 1957). The rate of destruction of ascorbic acid by cobalt 60 irradiation is proportional to the dose administered. After four months storage, however, rate of loss from irradiated and nonirradiated tubers is about the same. Schwimmer et al (1958) found that ascorbic acid increases immediately after irradiation, but decreases after one day to the same concentrations as those untreated.

Effect of method of cooking and processing

Vitamin C is reduced during most methods of cooking and processing. Losses during boiling or steaming of peeled potatoes varies between 14 and 30 percent between varieties. In boiling unpeeled potatoes there is very little or no loss in vitamin C. Retention of ascorbic acid when potatoes are cooked with just enough water to keep them covered it is about 80 percent retention (Weits and Lassche 1960). The median value of biological available ascorbic acid is 11.5 - 13.5 mg. per 100 gm. for cooked new potatoes and 1.7 - 2.9 mg. for cooked stored potatoes.

The highest loss, up to 50 percent, occurs in fried potatoes.

French fried potatoes lost 16 to 35% of the ascorbic acid while oven browned and hashed browned lost about 2/3 of the vitamin.

An extensive study of large scale cooking of potatoes was reported by Streightoff et al (1946). Their raw potatoes contained 16 to 27 mg. of ascorbic acid per 100 gm. Only 5% of this was lost in steaming while 24 to 68% was lost in mashed potatoes depending upon how long they were held after mashing. Baked potatoes lost 28% of the ascorbic acid and those which were boiled lost only 13%. The recommended daily dietary allowance for mature men is 60 mg. ascorbic acid as established by the Food and Nutrition Board, National Academy of Sciences -- National Research Council (1968).

Losses in ascorbic acid which occur during various forms of processing potatoes will be presented further in section III.

The B Vitamins

Potatoes contribute worthy amounts of three of the B vitamins, niacin, thiamine and riboflavin. The B vitamins as a group are essential not only for general health and growth, but for carbohydrate metabolism, smooth functioning of the nervous system, normal digestion and health of skin.

Streightoff et al (1946) found in raw potatoes in mg. per 100 gm., niacin, 1.7 - 3.3, thiamine 0.08 - 0.13 and riboflavin 0.03. There was little loss of any of the three vitamins (greatest loss was 17%) when potatoes were mashed , boiled steamed or baked.

Raw potatoes grown in Wisconsin showed niacin content of 1.54 mg. per 100 gm. Tubers stored at 40°F. increased in niacin content during the first month and then decreased to about the initial level after 6 months storage. Baked potatoes lost 4.2% of their original niacin content. A 100 gm. serving of boiled or baked potatoes supplies approximately 1/10 of the daily allowance for niacin (Page and Hanning 1963).

In India Choudhuri et al (1963) found thiamine content ranged from 0.09 to 0.110 mg. per 100 grams of potatoes. The median value for boiled potatoes found in Wisconsin was 0.082 mg. (Hanning and Mudambi 1962).

The recommended daily dietary allowance for mature men is 17 mg. equivalents niacin, 1.3 mg. thiamine and 1.7 mg. riboflavin as established by the Food and Nutrition Board, National Academy of Sciences--National Research Council (1968).

The following table presents the composition of 100 grams of raw and most cooked and processed forms of potatoes (Watt and Merrill 1963).

The effect of processing potatoes on the content of B vitamins will be presented in section III.

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Composition of foods, 100 grams, 3-1/2 oz. edible portion
(Parentheses indicate imputed value)

	Water	Food energy	Protein	Fat	Carbohydrate Total	Carbohydrate Fiber	Ash	Calcium	Phosphorus	Iron	Vitamin A value	Thiamine	Riboflavin	Niacin	Ascorbic acid
	Pct.	Cal.	Gm.	Gm.	Gm.	Gm.	Gm.	Mg.	Mg.	Mg.	I. U.	Mg.	Mg.	Mg.	Mg.
POTATOES															
Raw	79.8	76	2.1	0.1	17.1	0.5	0.9	7	53	0.6	20	0.10	0.04	1.2	20*
Cooked:															
Baked in skin	75.1	93	2.6	0.1	21.1	0.6	1.1	9	65	0.7	20	0.10	0.05	1.7	20
Boiled in skin	79.8	76	2.1	0.1	17.1	0.5	0.9	7	53	0.6	20	0.10	0.04	1.5	16
Boiled, pared before cooking	82.8	65	1.9	0.1	14.5	0.5	0.7	6	56	0.7	20	0.09	0.03	1.2	16
French fried	44.7	274	4.3	13.2	36.0	1.0	1.8	15	111	1.3	50	0.13	0.11	3.1	21
Fried from raw	46.9	268	4.0	14.2	32.6	1.0	2.3	15	101	1.1	40	0.12	0.07	2.8	19
Hash-browned after holding overnight	54.2	229	3.1	11.7	29.1	0.8	1.9	12	79	0.9	30	0.08	0.05	2.1	19
Mashed, milk added	82.8	65	2.1	0.7	13.0	0.4	1.4	24	49	0.4	40	0.08	0.05	1.0	10
Mashed, milk and table fat added	79.8	94	2.1	4.3	12.3	0.4	1.5	24	48	0.4	260	0.08	0.05	1.0	9
Canned:															
Solids and liquids	88.5	44	1.1	0.2	9.8	0.2	0.4	(4)	(30)	(0.3)	10	0.04	0.02	0.6	13
Dehydrated mashed:															
Flakes without milk:															
Dry form	5.2	364	7.2	0.6	84.0	(1.6)	3.0	35	(173)	1.7	Trace	0.23	0.06	5.4	32
Prepared, water, milk, table fat added	79.3	93	1.9	3.2	14.5	0.3	1.1	31	47	0.3	130	0.04	0.04	0.9	5
Granules without milk:															
Dry form	7.1	352	8.3	0.6	80.4	1.4	3.6	44	203	2.4	Trace	0.16	0.11	4.9	19
Prepared, water, milk, table fat added	78.6	96	2.0	3.6	14.4	0.2	1.4	32	52	0.5	110	0.04	0.05	0.7	3
Granules with milk:															
Dry form	6.3	358	10.9	1.1	77.7	1.5	4.0	42	237	3.5	60	0.19	0.30	4.2	16
Prepared, water, table fat added	81.4	79	2.0	2.2	13.1	0.3	1.3	31	44	0.6	90	0.03	0.05	0.8	3
Frozen:															
Diced, to hash-brown:															
Not thawed	81.0	73	1.2	Tr.	17.4	0.4	0.4	10	30	0.7	Trace	0.07	0.01	0.6	9
Cooked, hash-browned	56.1	224	2.0	11.5	29.0	0.7	1.4	18	50	1.2	Trace	0.07	0.02	1.0	8
French-fried:															
Not thawed	63.5	170	2.8	6.5	26.1	0.6	1.1	7	67	1.4	Trace	0.14	0.02	2.1	20
Heated	52.9	220	3.6	8.4	33.7	0.7	1.4	9	86	1.8	Trace	0.14	0.02	2.6	21
Mashed:															
Not thawed	80.4	75	1.7	0.1	17.1	0.4	0.7	16	39	0.7	30	0.07	0.03	0.8	6
Heated	78.3	93	1.8	2.8	15.7	0.4	1.4	25	42	0.6	140	0.06	0.04	0.7	4
POTATO CHIPS	1.8	568	5.3	39.8	50.0	(1.6)	3.1	40	139	1.8	Trace	0.21	0.07	4.8	16
POTATO FLOUR	7.6	351	8.0	0.8	79.9	1.6	3.7	33	178	17.2	Trace	0.42	0.14	3.4	(19)

* Year round average. Recently dug potatoes contain about 24 mg. of ascorbic acid per 100 gm. The value is only half as high after 3 months of storage and about <u>one third</u> as high when potatoes have been stored as long as six months.

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III. PROCESSED QUALITY OF POTATOES

Commercially prepared potato products are increasingly replacing potato products made in the home and restaurants from fresh potatoes. In the United States this trend is rapidly in progress and today over 50% of all potatoes eaten in that country are in processed form. In many other countries the trend is in the same direction and the percent of the total that is processed commercially extends from below 50% to zero in many countries. But I believe we should be looking into the future and anticipate that some form of potato processing will be utilized in essentially all potato producing countries in the world. Therefore, we should be interested in any changes nutritionally which may result from the various methods of processing potatoes. Murphy et al (1966) obtained nine potato products in one or more market forms which were analyzed, in most instances before and after cooking or other preparation. A home prepared form, with the exception of chips, was included in the analysis. Data in the following table show that there are no marked differences in food energy, protein or ash between the home prepared and commercially processed items.

Proximate composition of ready to eat potato products prepared from different market forms. (condensed from Murphy et al 1966).

Product	Food Energy cal/100 gm	Fat gms/100 gm	Protein gm/100 gm	Ash gm/100 gm	Carbohydrate (by difference) gm/100 gm
Mashed					
home recipe	77	0.5	2.2	0.97	16.2
Av. 4 brands dehydrated mix	83	1.3	2.2	1.17	16.1
French fries					
home recipe	224	8.8	4.9	1.90	32.9
Av. 7 brands frozen—oven heated	263	10.4	3.8	1.57	41.2
Scalloped					
home recipe	98	3.0	3.0	1.51	15.2
Av. 2 brands dehydrated mix	104	2.5	2.5	1.86	18.6
Chips					
Av. 4 brands	531	33.9	7.2	4.27	52.5

Proteins and amino acids

The content of several forms of cooked and processed potatoes in essential amino acids has been shown by Wertz et al (1956) and presented in the next table. In the study of data of this nature one must think in terms of foods with equal amounts of water or solids. For instance, boiled potatoes are about 80% water when eaten, bread is only about 35% water and potato chips are about 2%.

Amino acids of potatoes cooked in various ways and of white bread.

	mg per 100 gm.								
Method of cooking	iso-leucine	leucine	lysine	meth-ionine	phenyl-alanine	threo-nine	trypto-phane	valine	Total
boiled	0.89	1.09	1.10	0.26	0.86	0.76	0.24	1.19	6.39
chips	3.46	4.21	3.66	0.92	2.79	2.48	0.57	4.22	22.31
French fry	2.89	2.25	2.03	0.47	1.57	1.47	0.45	2.48	13.61
mashed	1.21	1.54	1.31	0.35	1.04	1.02	0.22	1.25	7.94
white bread	5.51	7.94	2.54	1.62	5.29	3.32	0.89	5.46	32.57

From Wertz et al (1956)

Anisimova (1969) determined amino acids by paper chromatography in acid hydrolyzates of 12 varieties of fresh and cooked potatoes in Russia. Loss from cooking was 14-21%. Schwerdtfeger (1969) in Germany quantitatively determined 19 amino acids obtained by acid or alkaline hydrolysis from raw potatoes and from boiled and fried and from dumplings and salad. A significant decrease in total amino acid content occurred only with dumplings.

On dehydration of potatoes in West Pakistan least losses occur in protein and the highest in reducing sugar, while starch, sucrose and ash losses are intermediate (Bhatti et al 1968). Rios Iriarte et al (1972) using the biuret and Kjeldahl methods of determination found the protein content of six potato cultivars ranged from 5.5 to 8.7 gm per 100 gm in potato flakes. Compared with that of the whole egg, threonine, lysine, histidine and tyrosine levels in potato flakes were about the same as whole egg; leucine, phenylalanine, arginine, isoleucine and methionine levels were higher in whole egg, but aspartic acid and glutamic acid levels were much higher in the flakes than in whole egg. With 5.28% potato flake protein in the diet, the essential amino acid levels supported vole growth. Protein efficiency ratios (PER) were lower than that for a casein diet. The lowest chemical score was found for methionine, ranging from 19 to 31 between the cultivars. With methionine-supplemented diets with the exception of cultivar 58, the vole weight gains attributable to supplementation were equal to or greater than the gains on the nonsupplemented diets. The apparent absorbability of potato proteins in unsupplemented and methionine-supplemented diets ranged from 55.3 to 63.8% and 69.5 to 88.6% respectively; that of casein was 64.5%.

Peare and Thompson (1973) prepared a potato flour concentrate by air classification techniques to remove the large starch grains. From the 13% whole potato flour they obtained a 33% concentrate comprising a highly nutritious protein. When fed in cooked form to weanling rats no differences were found in food consumption or protein quality between whole potato flour and the concentrate derived from it. Based on protein efficiency ratios, nitrogen incorporation efficiencies (NIE) and weight gain measurements, the responses of rats fed potato diets as a percent of the responses of rats fed casein were 76, 74, and 68% respectively. The protein quality of the potato flours as determined by a microbiological method utilizing S. zymogenes was comparable to that determined by rat assay.

Kies and Fox (1972) report that methionine was the first limiting amino acid in dehydrated potato flakes for human nutrition. The mean N balances for seven human adults fed 4.0 gm. N per day from dehydrated potato flakes and 0.68 gm N from the basal diet were compared with those after supplementation with L-methionine, L-leucine, L-phenylalanine, or all three amino acids. The mean N balances were -1.18, -0.27, -0.83, -0.91 and -0.30 gm. N per day respectively. Subjects showed increase in N retention when methionine was used as a dietary supplement either singly or in combination with leucine or phenylalanine. Addition of purified L-methionine at a level equivalent to 0.37%, basis potato flakes, could significantly improve the protein nutritive value of the flakes. Sensory panel evaluation indicated the palatability was not adversely affected up to 1% supplementation.

Low specific gravity (1.065-1.075) Netted Gem potatoes lost about 40% of their total amino acid content by canning or chipping. Loss in drum dried flakes was about 20% and 4.5% in French fries. High specific gravity potatoes (1.095-1.106) showed a similar trend but the losses were much smaller. All processing methods reduced the available lysine content; chips and canned potatoes had the greatest loss followed by drum dried and French fried potatoes.

Vitamin A

Although this vitamin occurs in potatoes in very low amounts, it is possible to fortify processed products such as potato flakes with vitamin A. Cording et al (1961) showed that vitamin A content gradually decreased in dehydrated potato flakes in storage but was more stable when packed under nitrogen than in air.

Ascorbic acid

Watt and Merrill (1963) present as a year round average of ascorbic acid in raw potatoes 20 mg. per 100 gm. Dehydrated potatoes contain from 2.4 to 20.4 mg. per 100 gm. (Hanning and Mudambi 1962). Bring (1962) reported that reconstituted flakes contain approximately 1/4 as much vitamin C as raw potatoes and about 2/5-1/2 as much as fresh mashed potatoes. Total ascorbic acid in raw potatoes, fresh mashed potatoes and reconstituted dehydrated potato flakes made in a commercial plant in Idaho was 29.3, 18.8, and 8.0 mg. per 100 gm. respectively in October; 11.7, 8.2 and 3.1 mg. per 100 gm., respectively in February; and 10.6, 6.8, and 2.8 mg. per 100 gm., respectively in May. Total ascorbic acid retention in fresh mashed potatoes compared with the raw potatoes was 64.0-69.7% on an "as served" basis or 75.1-77.6% on a dry weight basis. Total ascorbic acid retention in the reconstituted dehydrated flakes compared to the raw potatoes was 26.1-27.2% on an "as served" basis or 36.5-40.0% on a dry weight basis. Moisture content of the raw potatoes was 76.6%, in fresh mashed potatoes, 79.9%, and in reconstituted dehydrated flakes 83.8% (Bring et al 1963). Ascorbic acid loss of dehydrated potatoes after two years storage at 41-82°F. in nitrogen was 29%; after three years it was 67%. No dehydroascorbic acid was found. Moisture and pH had no bearing on ascorbic acid values (Schillinger and Zimmerman 1965). Bring and Raab (1964) found that dehydrated flakes and dehydrated granules sampled in October of 1960, 1961, and 1964 contained respectively 8.0 and 6.6 mg. total ascorbic acid per 100 gms. sample as served. These same potato products sampled near the end of the processing season contained 2.8 and 2.1 mg. total ascorbic acid per 100 gms. moist flakes and granules, respectively. In general, total ascorbic acid retention in fresh mashed potatoes compared with raw potatoes in October and April was 51.7 and 47.4% respectively, on an "as served" basis. Total ascorbic acid retention in the reconstituted granules compared with raw potatoes in October and April was 25.3 and 18.0% respectively, on an "as served" basis.

Cording et al (1961) found that the level of ascorbic acid is maintained in dehydrated potato flakes at all storage temperatures for 28 weeks when the flakes are nitrogen-packed, but there are steady losses with air-packing.

Commercial brands of dehydrated potato products are different in their content of ascorbic acid. Fresh cooked potatoes contain 2 to 3 times more ascorbic acid than any of the cooked dehydrated unfortified potato products. Myers and Roehm (1963) stated that it would be well to fortify dehydrated potato products with ascorbic acid.

This is now being done. Dehydrated instant potatoes to which ascorbic acid has been restored have been added to the list of foods recommended for Federally-reimbursed school lunches under the National School Lunch Program.

Composition of potatoes and other foods (100 gms. edible portion).

Food	Water %	Food energy (cal.)	Pro-tein gm	Fat gm	Total carbo-hydrate gm	Cal-cium mg	Phos-phorus mg	Iron mg	Potas-sium mg	Vit A IU	Thia-mine mg	Ribo-flavin mg	Niacin mg	Ascorbic acid mg
Potatoes														
Raw	79.8	76	2.1	0.1	17.1	7	53	0.6	407	trace	0.10	0.04	1.5	20
Baked in skin	75.1	93	2.6	0.1	21.1	9	65	0.7	503	"	0.10	0.04	1.7	20
Boiled in skin	79.8	76	2.1	0.1	17.1	7	53	0.6	407	"	0.09	0.04	1.5	16
Boiled, peeled	82.8	65	1.9	0.1	14.5	6	42	0.5	285	"	0.09	0.03	1.2	16
Bread														
White unen-riched	35.8	269	8.7	3.2	50.4	70	87	0.7	85	"	0.09	0.08	1.2	trace
White enriched	35.8	269	8.7	3.2	50.4	70	87	2.4	85	"	0.25	0.17	2.3	"
Pumper-nickel	34.0	246	9.1	1.2	53.1	84	229	2.4	454	0	0.23	0.14	1.2	0
Beans														
Red, raw	10.4	343	22.5	1.5	61.9	110	406	6.9	984	20	0.51	0.20	2.3	-
Red, cooked	69.0	118	7.8	0.5	21.4	38	140	2.4	340	trace	0.11	0.06	0.7	-
Mung, cooked	91.0	28	3.2	0.2	5.2	17	48	0.9	156	20	0.09	0.10	0.7	6
Rice														
White, unen-riched cooked	72.6	109	2.0	0.1	24.2	10	28	0.2	28	0	0.02	0.01	0.4	0
*		2600	65			800	800	10		5000	1.3	1.7	17	60

Selected from Watt and Merrill (1963) Composition of foods, raw, processed, prepared. U.S. Dept. Agr. Agriculture Handbook N° 8.

* Recommended daily dietary allowances for male 35-55 years of age. Food and Nutrition Board, National Academy of Sciences - National Research Council. Seventh Edition 1968.

One-half cup serving of reconstituted dehydrated instant mashed potatoes meeting the industry vitamin restoration standard is included with the foods listed by the USDA as good sources of ascorbic acid for meeting children's needs for this vitamin. The dehydrated product is fortified with approximately the same amount of ascorbic acid as that lost during processing. This amounts to about 20 mg. per 1/2 cup of edible portion.

Total ascorbic acid content of raw potatoes, those freshly fried and those heated as frozen shoe string potatoes was 26.5, 43.2 and 27.6 mg. per 100 gm. soon after harvest and 12.2, 23.6, and 9.7 mg. per 100 gm. when processed after 5 1/2 months storage, respectively. Storage of frozen shoestrings up to 5 1/2 months does not significantly change the concentration of vitamin C (Bring 1966). During deep frying in oil vitamin C of potatoes decreased to 85% of that of the raw potato, which was 11.0-19.9 mg. per 100 gm. Vitamin C loss increases with time between initial frying and reheating (DeJongh and Tjolma 1961).

Vitamin C content in a variety of potato products ranges from 2.7 in potato powder to 20 mg. per 100 gm. in French fried potatoes (Kouwenhoven 1964).

B vitamins

Thiamine, riboflavin and niacin are relatively stable in dehydrated potato flakes under both nitrogen and air. Considerable losses in thiamine occur during processing because of the use of sulfite. Flakes fortified with a mixture of B vitamins and ascorbic acid and with a mixture of all the vitamins were considered unacceptable because of what was called "vitamin flavor" (Cording et al 1961). Thiamine, riboflavin and niacin were stable in dehydrated potatoes stored up to three years under nitrogen at 41-82°F. even in opened containers which were then stored for two months in the dark in air (Schillenger and Zimmermann 1965). Hanning and Mudambi (1962) found the amount of thiamine in dehydrated potatoes fluctuates considerably from 0.004 to 0.292 mg. per 100 gm.

In canned potatoes the average value of thiamine is 0.036 mg. per 100 gm. of drained product. This value is considerably lower than the median value found for boiled potatoes, 0.082 mg. per 100 gm. (Hanning and Mudambi 1962). Hentschel (1969) reports only a slight decrease in thiamine when potatoes are boiled, but a loss of 35-40% on frying. Riboflavin is lost to the extent of 5-30% in fried potatoes. Niacin decreases 25-30% with boiling but loses only 5-10% by frying.

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IV. CHEMICAL ANALYSES USED FOR DETERMINING POTATO QUALITY

Each participant in the workshop is requested to have specific suggestions for techniques and methods to be used for the determination of potato quality. These will be pooled at the workshop, discussed and hopefully decisions will be made as to the best methods to be recommended for use by the Potato Center.